

PRONGHORN RESPONSE TO COYOTE CONTROL— A BENEFIT: COST ANALYSIS¹

RONALD H. SMITH, Arizona Game and Fish Department, Phoenix, AZ 85023

DON J. NEFF, Arizona Game and Fish Department, Flagstaff, AZ 86001

NORMAN G. WOOLSEY, Arizona Game and Fish Department, Phoenix, AZ 85023

The population of pronghorns (*Antilocapra americana*) on Anderson Mesa in north-central Arizona has exhibited a strong correlation between coyote (*Canis latrans*) suppression and pronghorn fawn survival over the last 40 years (Arrington and Edwards 1951, Neff and Woolsey 1979). Similar relations have been reported with pronghorns in Utah (Udy 1953) and Texas (Hailey 1979) and with white-tailed deer (*Odocoileus virginianus*) in Texas (Guthery and Beasom 1977) and Oklahoma (Stout 1982).

The Anderson Mesa herd gradually declined after about 1955, and was reduced 85% by a blizzard in 1967 (White 1969). By 1970 the 115 survivors had increased to 350. Intensive annual coyote control by toxicants was then terminated. The herd peaked at 481 in 1971 and increased no further. Age ratios dropped from 90 fawns/100 does in 1975 to a low of 14 in 1979. Beginning in 1979 experiments were conducted to determine if coyote densities could be reduced sufficiently to affect fawn survival rates and allow the population to increase (Neff et al. 1985). The coyote population was effectively reduced over a 3-year period (1981-1983) by helicopter gunning after trapping and shooting had proved inadequate. This control effort, conducted just prior to fawning, has been coincidental with more than a 400% increase in the pronghorn population of the study area from 1980 to 1983.

This paper describes a computer simulation

model that was used to forecast the accumulated economic benefits and pronghorn populations resulting from each of 8 coyote control schedules.

STUDY AREA

Anderson Mesa, primarily pronghorn summer range, consists of a basalt-capped plateau that rises in the ponderosa pine (*Pinus ponderosa*) forest near Flagstaff and extends southeast about 65 km. The mesa top comprises about 500 km². The rolling surface is about 2,100 m in elevation, much of it open grassland invaded by pine and pinyon-juniper (*P. edulis*-*Juniperus utahensis*). The mesa lies entirely within Wildlife Management Unit 5B. The eastern slope of the mesa is a dense old-growth pinyon-juniper woodland, falling away to shortgrass and saltbush (*Atriplex* spp.) (Great Basin desert scrub (Brown 1982:329)) plains. These plains to the east of the mesa make up the balance of Unit 5B and are mainly pronghorn winter range. The entire management unit is about 1,500 km². Pronghorns migrate each spring to the mesa top before fawns are born. This spring range produces an abundance of palatable cool season forbs and grasses that provide a relatively high plane of nutrition for pregnant and lactating does. The mesa is grazed by cattle only, under supervision of the Coconino National Forest.

A central portion of Anderson Mesa (Pine Hill study area) was selected for intensive observations of coyotes and pronghorns because of the expanse of country (90 km²) that could be viewed and because it is an important fawning ground.

METHODS

Coyote Control

Coyote population reduction was contracted to the Animal Damage Control Division (ADC), U.S. Fish and Wildlife Service. From 1974 to 1980 trapping was conducted during April, May, and June. The trapping effort was concentrated on the antelope summer range on Anderson Mesa. The total effort in man-days (Table 1) varied among years because of weather conditions and ease of access. In 1980 the Arizona Legislature amended the laws to allow coyote shooting from aircraft under permit from the Arizona Game and Fish

¹ A contribution of Federal Aid in Wildlife Restoration Project W-78-R, Arizona Game and Fish Department in cooperation with the Animal Control Division, U.S. Fish and Wildlife Service, and the Coconino National Forest.

Table 1. Cost of coyote reduction on Anderson Mesa, Arizona, by the U.S. Fish and Wildlife Service, Animal Damage Control Division, 1977-1983.

Year	Coyotes taken	Method	Effort		Unadjusted costs		1983 adjusted costs	
			Man-days	Flight hours	Total	Per coyote	Total	Per coyote
1977	54	Trap	65		\$ 2,937.92	\$ 54.41	\$ 4,321.13	\$ 89.29
1978	31	Trap	50		3,447.88	111.22	5,358.02	169.61
1979	29	Trap	101		5,395.78	269.78	7,392.22	369.60
1980	42	Trap	99		7,577.78	180.42	9,146.38	217.77
1981	11	Trap	60		3,869.00	351.73	4,232.69	384.79
	62	Helicopter gunner	6	34.7	16,785.05*	270.73	18,362.84	296.18
1982	60	Helicopter gunner	6	35.3	16,314.72	271.91	16,804.16	280.07
1983	70	Helicopter gunner	6	30.0	16,458.00	235.11	16,458.00	235.11

* Approximately 34% of helicopter cost was for services of ADC personnel.

Commission for control of depredations. From 1981 to 1983 the ADC used helicopter gunning as their primary coyote reduction method on about 490 km² of Anderson Mesa. The schedule of flight operations for the 3 years was consistent. Monthly flights were conducted on 3 or 4 consecutive days in March, April, and May (Table 1). It was felt that control just prior to fawn birth would effect a temporary reduction in coyote numbers in the immediate vicinity of fawning grounds sufficient to improve fawn survival through the first 4-5 weeks.

The average cost/coyote by trapping was \$193.51 (1983 adjusted cost = \$246.21) for 158 coyotes in 5 years. By helicopter gunning it was \$259.25 (1983 adjusted cost = \$270.45) for 192 coyotes in 3 years.

Coyote and Pronghorn Population Response

The effect of varying intensities and methods of coyote control on both coyotes and pronghorns was inferred from trends in ground observation indices and aerial composition counts during 1977-1983.

Because Anderson Mesa is the principal fawning area for pronghorns occupying Unit 5B, parameters of the herd occupying the larger area were used to evaluate response to coyote control.

Each year during the May-June fawning period 1 observer (D. J. Neff) with a 20X spotting scope watched for 5-3 hours at dawn and again at dusk from a tower on Pine Hill. Locations, numbers, sex and age ratios, and details of pronghorn behavior were recorded. Observations/hour of adult and fawn pronghorns and coyotes were calculated as indices to density.

Standardized aerial surveys are flown annually on all Arizona pronghorn ranges in June or July. In Unit 5B, survey subdivisions allowed us to compile data separately for Pine Hill, Anderson Mesa, or the whole

unit. All pronghorns seen were classified as bucks, does, or fawns. These standardized surveys allowed us to use all other pronghorn management units as untreated experimental controls during 1981-1983 when only Unit 5B had helicopter gunning.

On Anderson Mesa a small number of coyotes was trapped and radio-collared each year (by N. G. Woolsey). This allowed us to make a crude estimate of coyote density with the Lincoln Index based on marked animals taken by the helicopter.

Overview—Benefit: Cost Evaluation

Evaluation of the ultimate benefits of the control strategy used on Anderson Mesa is based on the estimated economic value of male pronghorns available to hunters in Unit 5B as reflected in the dollars spent by hunters relative to the cost of coyote control methods. A major assumption is that the recent pronghorn population increase in Unit 5B is a direct effect of coyote control and that future population changes will reflect how coyotes are managed in this area.

On the basis of this assumption, we built a computer model that calculates the net economic benefits of 8 simulated coyote control strategies. These strategies were based on a repetition of the aerial control methods described herein, but scheduled in a variety of arbitrary year-combinations over a 10-year period, 1983-1992.

The rationale of the simulation model was as follows: based on a demonstrated relationship between fawn: doe ratios and the number of years since coyote control, a simulated coyote control schedule produced an annual estimate of the fawn: doe ratio. This ratio drove a second population model that yielded an annual estimate of male pronghorns available for harvest. A management guideline and formula allocated a certain number of hunting permits for Unit 5B. These

DL—

23

cast the accumu-
l pronghorn pop-
of 8 coyote con-

horn summer range,
au that rises in the
1) forest near Flag-
5 km. The mesa top
ling surface is about
open grassland in-
r (*P. edulis-junip-*
rely within Wildlife
n slope of the mesa
er woodland, falling
triplex spp.) (Great
329)) plains. These
e up the balance of
winter range. The
1,500 km². Prong-
sa top before fawns
es an abundance of
asses that provide a
for pregnant and
by cattle only, un-
ational Forest.
esa (Pine Hill study
ervations of coyotes
nse of country (90
ecause it is an im-

is contracted to the
(ADC), U.S. Fish
1980 trapping was
June. The trapping
lope summer range
in man-days (Table
weather conditions
Arizona Legislature
shooting from air-
na Game and Fish

permits generated an annual economic benefit by way of the gross expenditures associated with hunting. These benefits were summed over the 10-year simulation period. The total of the fixed costs of the coyote control operation were deducted from the accumulated benefits, yielding a net 10-year benefit. This figure was then compared with the net benefit derived from the control schedule employing coyote control in 1983 only, hereinafter referred to as the no-control alternative. The resulting ratio was used as the net benefit ratio. The various model inputs are discussed in turn.

Fawn: Doe Ratios

Summer fawn:doe ratios as obtained during July aerial surveys for the period 1951-1979 were negatively correlated ($r = -0.86$, $P \leq 0.01$) with the number of years since the last effective coyote control had been administered on Unit 5B. A year of effective control is defined as a year prior to 1972 when ADC personnel placed 1080 baits on Unit 5B and substantial numbers of coyotes were judged to have been killed. The fawn:doe ratio (Y) is estimated by $Y = 72.57 - 11.40X$ where $X =$ years since coyote control with 1080.

The ratio during years of 1080 control ($X = 0$) was estimated at 73 fawns/100 does. We felt that this was not a reasonable functional relationship to use in our net benefit model because the 3 years of aerial gunning produced an average 57 fawns/100 does. The earlier 1080 control was judged to be much more effective because baits were placed in the fall and were available to coyotes until roads became passable in the spring, permitting ADC personnel to remove the baits. This effectiveness was not likely equaled by aerial gunning limited to the period just prior to the birth of fawns.

We adjusted the regression equation for use in our net benefit model in 2 ways. The mean ratio of 57 fawns/100 does was used as the Y intercept. We also assumed that the fawn:doe ratio (Y) would not be a linear function of years since control beyond 3 years without control. The average fawns/100 does for the 10 years when ≥ 4 years had elapsed since control was 31. We chose a lower estimate for those years equal to the value of Y when $X = 3$. The adjusted, segmented regression model is $Y = 57 - 11.4X$ when $X \leq 2$ and $Y = 23$ when $X > 3$.

Pronghorn Population Estimates

The fawn:doe ratios thus obtained were put into a simple population dynamics model (R. Miller, Ariz. Game and Fish Dep., pers. commun.) that adds animals to the population relative to the fawn:doe ratios recorded on surveys and takes animals from the population based on estimates of hunting and natural mortality. Hunting mortality estimates, considered reliable, were obtained from a questionnaire to pronghorn hunters; about 74% of all hunters were sampled. This model used the initial 1974 aerial count of bucks, does,

and fawns as the beginning population. Yearly population estimates were then generated for 1974-1984, using yearly fawn:doe ratios obtained from surveys, and the kill of bucks in Unit 5B. Natural mortality was assumed to be constant for the period and was input to the first iteration of the model as a guess. The model was then iterated with different estimates of natural mortality in each of the 3 population cohorts until the population response approximately paralleled a graph of the actual pronghorn counts for the same 11-year period. The mortality rates that produced the best fit of modeled to actual data were then used as inputs to the same model to forecast population estimates for 1983-1992.

Economic Benefits

Our evaluation of benefits was based on the economic value of hunting male pronghorns. Cost of a permit to the hunter and the number of permits issued are the factors that drive the benefit side of the model. Value of a permit includes both the permit fee and expected expenditures/man-day of hunting. We consider gross expenditures/hunter-day to be a valid measure of relative value in a model in which number of permits is the primary variable. It is a reasonable assumption that hunter demand would absorb all permits offered within our model projections.

During 1984 the resident permit fee was \$53. The average 1980 cost/big game hunter-day was estimated at \$52 (Anon. 1980) and adjusted to \$63 in 1983 dollars. The 1950 estimate was modified by deleting expenditures unrelated to pronghorn hunting (e.g., hunting dogs). Arizona pronghorn hunts have been fixed at 3 days for many years and hunters have averaged 2.17 days afield over the past 10 years.

The net benefit model was designed to simulate an estimated number of bucks that would be produced during the period 1983-1992 in response to each of a set of 8 coyote control strategies. Estimated buck numbers is the primary variable determining number of buck permits allocated each year. In Unit 5B, 50 bucks are allocated for harvest for every 100 bucks seen during aerial surveys. Hunter success in recent years has averaged 61% and hunter participation has averaged 96.7% of the permits issued, thus allowing 87 permits to be issued for every 100 bucks counted on survey. The economic value of each permit in 1983 dollars was estimated as follows: let 0.033 = proportion of nonparticipants, 0.067 = proportion of participants, \$53 = value of permit and application fee, 2.17 = average days afield/participant, \$63 = value of a 1983 recreation day, and X = number of permits allocated. Then total annual benefit (B) = $X(0.033)(53) + X(0.967)(53 + (2.17)(63)) = 185.18X$.

Costs

Actual costs (Table 1) for 3 years of aerial gunning were averaged and adjusted to 1983 dollars by reference to cost-price index data (Anon. 1983). This av-

population. Yearly population estimates for 1974-1984, obtained from surveys, were used as input to the model. Natural mortality was estimated as a guess. The model produced estimates of natural mortality cohorts until they paralleled a graph for the same 11-year period. The best fit was then used as input to the population estimates for

based on the economic costs. Cost of a permit to hunt was \$53. The cost of permits issued are on the side of the model. The permit fee and the cost of hunting. We conclude that the model may be a valid means in which number of permits is a reasonable assumption. It is a reasonable assumption that all permits would absorb all permit fees. The permit fee was \$53. The cost of hunting was estimated to be \$63 in 1983 dollars by deleting the cost of hunting (e.g., hunters have been fixed at \$53). The average cost of hunting was 2.17.

assigned to simulate an average response to each of a simulated buck number. The number of permits in Unit 5B, 50 bucks, 100 bucks seen during the 1979 season. In recent years, the number of permits has averaged 87 permits counted on survey. The permit fee in 1983 dollars was \$53. The proportion of permits allocated to participants was 2.17 = average value of a 1983 permit fee divided by the proportion of permits allocated, $2.17 = X(0.033)/(53) + X$.

of aerial gunning was \$3 dollars by reference to 1983. This average

Table 2. Pronghorn and coyote observations/hour, Pine Hill study area, Anderson Mesa, Arizona, 1977-1983.

Year	Hours	Pronghorn		Coyotes
		Adults	Fawns	
1977	84.3	17.7	4.7	0.16
1978	87.5	18.5	1.9	0.40
1979	106.3	10.9	0.5	0.86
1980	123.3	11.3	1.5	0.30
1981	101.2	25.7	6.4	0.17
1982	87.8	37.9	16.7	0.15
1983	84.1	52.8	18.8	0.19

average level of effort and expenditure/year of coyote control is assumed constant for all control sequences modeled.

Coyote Control Simulation

The simulation model was run for 8 coyote control strategies: control in 1983 only; control every second, third, fourth, or fifth year; control in the first 2 and 3 consecutive years in 5 years; and control in the first 5 consecutive years in 10 years. Accumulated net benefits were calculated for a 10-year period beginning with the 1983 pronghorn population level. This was the last year as of this writing for which we had estimates of fawns/doe and hunter harvest; for this reason 1983 was chosen as the base year. This was, however, a year of coyote control. Consequently, our best simulation of a no-control strategy was control during the first year and none thereafter.

RESULTS

Cost and Effectiveness of Coyote Reduction

Kill/unit effort was fairly uniform from aerial gunning but varied widely for trapping (Table 1). Numbers of coyotes taken varied from 20 to 73/year, and costs/coyote varied from \$89 to \$385 for trapping and from \$235 to \$296 for aerial gunning. Average annual aerial gunning control cost (adjusted to 1983 dollars) was \$17,200.

Coyote Population Trends

Lincoln Index estimates of density were based on only 4-7 marked coyotes subject to aerial gunning each year. Reasonable and consistent estimates were obtained (0.66, 0.42, and

Table 3. Herd composition of pronghorns on Anderson Mesa, Arizona, 1977-1983 (winter range excluded).

Year	Bucks	Doe	Fawns	Total	Fawns/100 does
1977	40	205	67	312	33
1978	49	193	54	296	28
1979	51	161	11	223	7
1980	26	183	79	288	43
1981	47	269	137	453	49
1982	71	335	231	637	69
1983	112	437	293	842	67

0.42 coyotes/km² in 1981, 1982, and 1983, respectively) although precision of the estimates was low. Accuracy of the estimates was supported by observations on size and projected number of coyote breeding territories on Anderson Mesa (Neff et al. 1985). If density estimates were accurate, the removal of 73, 60, and 70 coyotes by the ADC represented about 22% of the total population in 1981, 28% in 1982, and 29% in 1983. Although this appears to be a low level of coyote removal in comparison with the marked response in pronghorn fawn survival, the loss of perhaps 30% of the breeding females and consequent disruption of denning activity may have had a disproportionately large effect on fawn survival.

Coyote activity on the Pine Hill study area increased rapidly in 1978 and 1979 (Table 2). Coyote observations reached a high of 0.86/hour during the 1979 fawning season. Coyotes were seen in groups of 3-5 (groups of 6 and 8 were reported) during this period, whereas no groups larger than 3 were seen during periods of lower density. Coyote observations declined substantially in 1980 and thereafter.

Pronghorn Fawn Survival

Aerial survey results (Table 3) indicated a gradual decline in numbers of adult pronghorns on Anderson Mesa from 1977 to 1979. Fawn survival was extremely low in 1979 but much improved in the next 4 years, and numbers of both adults and fawns increased rapidly. The total count for Anderson Mesa and

Table 4. Ten-year projection of benefits and costs of coyote control, Anderson Mesa, Arizona, 1983-1992.

Control schedule	Benefits	Cost	Net Benefit	Benefit ratios
First of 10 years	\$243,507	\$ 17,200	\$226,307	1.00
First of 2 years	519,981	86,000	433,981	1.92
First of 3 years	422,391	68,800	353,591	1.56
First of 4 years	354,985	51,600	303,385	1.34
First of 5 years	320,356	34,400	285,956	1.26
First 2 of 5 years	418,687	69,500	349,187	1.54
First 3 of 5 years	517,203	103,200	414,003	1.82
First 5 of 10 years	444,424	86,000	358,424	1.58

adjacent winter range in July 1983 was 1,008, exceeding 1,000 for the first time since 1960. Only 1 other range in northern Arizona showed a strong upward trend in pronghorn numbers during the period of this study. This area comprises Units 7 and 9, between the San Francisco Mountains and the Grand Canyon, about 167 km northwest of Unit 5B. Pronghorn counts increased in 1980 and again in 1983, with a combined total net gain from 261 to 382 adults plus yearlings, or 46%. During the same period numbers on Unit 5B, with 3 years of effective coyote control, increased from 317 to 747 adults plus yearlings, or 136%. The pronghorn survey counts in Units 7 and 9 were

not correlated ($P > 0.05$) with those in Unit 5B during 1979-1984. There was little evidence to suggest that the improved fawn survival on Anderson Mesa was associated with factors other than coyote control.

Benefit Evaluation

Accumulated net benefits were maximum for control applied 1 year in 2 and minimum for control in 1983 only (Table 4). The accumulated net benefits for most schedules did not exceed the accumulated net benefits for the no-control alternative until the fifth or sixth year of the simulation run, indicating that long-term planning of coyote management programs is needed. The favorable net benefit ratios at the end of the 10-year control cycle appear to reflect the fact that as pronghorns increase as a result of coyote reduction, the total number of harvestable bucks increases and there is an increasing payoff for the fixed annual cost of the control operations (Fig. 1).

SUMMARY AND CONCLUSIONS

The rapid increase in the pronghorn herd on Anderson Mesa from 1980 to 1983 was the result of a dramatic rise in the rate of fawn survival and recruitment. High fawn survival was strongly correlated with the removal of coyotes by helicopter gunning in spring prior to fawning. The increased fawn survival was not related to any observable change in pronghorn behavior or nutritional status (Neff and Woolsey 1979, Neff et al. 1985). We conclude

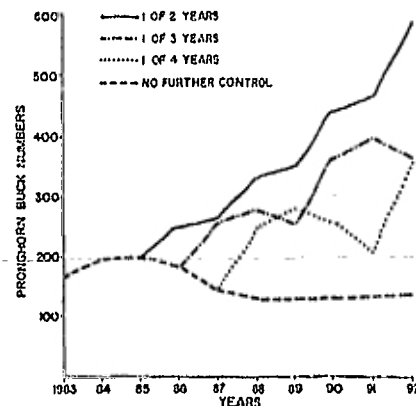


Fig. 1. Computer simulation of expected trends in buck pronghorn numbers under 4 coyote control strategies, Anderson Mesa, Arizona.

1, 1989-1992.

Benefit ratio
1.00
1.92
1.56
1.34
1.26
1.54
1.33
1.58

those in Unit
was little evi-
ved fawn sur-
associated with
1.

re maximum
and minimum
4). The accu-
schedules did
t benefits for
e fifth or sixth
dicating that
management
le net benefit
control cycle
s pronghorns
eduction, the
icks increases
for the fixed
tions (Fig. 1).

DISCUSSION

pronghorn herd
1983 was the
rate of fawn
fawn survival
e removal of
spring prior
survival was
nge in prong-
us (Neff and
We conclude

that the reduction in coyote numbers during the spring fawning period was directly responsible for the increased fawn survival.

Responses by the pronghorn herd to various schedules of coyote control, and the economic costs and benefits involved, were modeled on the assumption that coyote control on Anderson Mesa will be an element in pronghorn management in Unit 5B in the foreseeable future. The alternative of "no control" has attractions, including the avoidance of hazardous low-level flight and control work expense. It also leaves the coyotes for fur harvest and sport hunting. But the decline of the Anderson Mesa pronghorn herd from 1950 to 1967, and the period of stagnation from 1972 to 1980, indicates that this herd will not thrive under inaction. This supposition is supported by the computer simulations of pronghorn buck numbers under the "no control" schedule (Fig. 1) and by current trends in fawn survival in Unit 5B during 1984-1985. After 2 years since control of coyotes, the fawn:doe ratio declined to 0.47 in 1984 and to 0.26 in 1985. The regression estimates were 0.45 and 0.34 for those 2 years, respectively. The population, however, has performed somewhat better than the model predicted. The 1985 aerial survey yielded a count for 247 bucks where the model (Fig. 1) predicted 199.

No quantitative measurements were made of other factors, such as disease or abandonment, which could affect fawn survival. Subjective observations (Neff and Woolsey 1979) suggest that the Anderson Mesa fawning range generally provides an abundance of palatable and nutritious forbs and grasses. Management of cattle grazing is progressive and judicious. This range, however, is primarily a midgrass prairie lacking a shrub component. In view of the existing ecological conditions (winter snow

cover, heavy clay soils, native grasses and forbs in early phenological stages during pronghorn fawning) there appears to be no practical and economical opportunity for improvement in fawning cover.

Selective, time-specific application of aerial gunning thus appears a reasonable and economically beneficial means of increasing numbers of pronghorns in Unit 5B in the presence of high coyote densities.

LITERATURE CITED

- ANONYMOUS. 1980. 1980 national survey of fishing, hunting, and wildlife-associated recreation: Arizona. U.S. Dep. Inter. and U.S. Dep. Commer., Washington, D.C. 75pp.
- . 1983. Arizona statistical review. The Valley Natl. Bank, Phoenix, Ariz. 76pp.
- ARRINGTON, O. N., AND A. E. EDWARDS. 1951. Predator control as a factor in antelope management. Trans. North Am. Wildl. Conf. 16:179-193.
- BROWN, D. E., editor. 1982. Biotic communities of the American Southwest: United States and Mexico. Desert Plants 4(1-4):1-342.
- GUTHRIE, F. S., AND S. L. BEASOM. 1977. Responses of game and nongame wildlife to predator control in south Texas. J. Range Manage. 30:401-409.
- HARLEY, T. L. 1970. A handbook for pronghorn antelope management in Texas. Tex. Parks and Wildl. Dep., Fed. Aid Rep. Ser. 20. 59pp.
- NEFF, D. J., R. H. SMITH, AND N. W. WOOLSEY. 1985. Pronghorn antelope mortality study. Ariz. Game and Fish Dep. Final Rep., Fed. Aid Proj. W-78-R1 WP2, 116. 18pp.
- , AND N. W. WOOLSEY. 1979. Effect of predation by coyotes on antelope fawn survival on Anderson Mesa. Ariz. Game and Fish Dep., Spec. Rep. 8. 36pp.
- SROUT, G. G. 1982. Effects of coyote reduction on white-tailed deer productivity on Fort Sill, Oklahoma. Wildl. Soc. Bull. 10:329-332.
- UDY, J. R. 1953. Effects of predator control on antelope populations. Utah Dep. Fish and Game, Publ. 5. 48pp.
- WHITE, R. W. 1969. Antelope winter kill, Arizona style. Proc. West. Conf. Game and Fish Comm. 49:251-254.

Received 23 April 1985.

Accepted 10 December 1985.